A Dedicated Storage Ring For Far-IR Coherent Synchrotron Radiation at the ALS

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INTRODUCTION

In the last few years an always-increasing interest of the accelerator community has been addressed to coherent synchrotron radiation (CSR). Just as an example, people working in linear collider projects are carefully investigating the potentially dangerous effects that CSR can have on their bunch compressor schemes [1]. Others are instead interested in CSR as a new powerful source of synchrotron radiation to be used for experiments. Schemes using linacs as beam source, which have already demonstrated the capability of producing impressive amounts of CSR [2], belong to this category as well as the project of generating stable CSR in a storage ring presented in this paper. The idea of a CSR source based on a storage ring was first proposed in 1994 by J. Murphy but so far it has not realized. CSR production is presently limited to the far and very far infrared range. Vacuum chamber shielding limits the larger obtainable wavelength to few millimeters while the present capability of producing very short pulses constrains the minimum obtainable value within few hundred microns. One of the driving forces that triggered the idea of proposing this source for the ALS was that a very strong and dynamic community of potential far infrared users already exists and that the availability of such an intense source will open the way to a completely new set of possible experiments [3]. A strong scientific case involving eminent names of the far infrared community is being constructed.

The first observation of steady CSR at BESSY II [4] has recently demonstrated the feasibility of generating stable CSR in a storage ring.

The paper describes the main ideas for the design of a storage ring at the ALS dedicated to and optimized for the production of far-infrared CSR over the wavelength range from 200-1000 μm. In the proposed scheme the ring is located on top of the ALS Booster shielding, see Figure 1, and uses the ALS injector, with beneficial impact on the total cost. The scale of the project is expected to be comparable to a couple of ALS beamlines and the project itself can be considered as an extension towards the far infrared of the capabilities of the ALS.

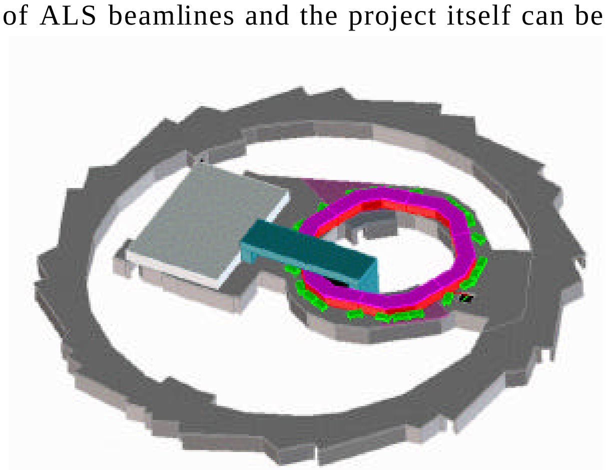

Figure 1: IR ring location atop the ALS booster synchrotron. The ring circumference is 66 m.

GENERATING CSR IN THE ALS FAR-IR RING

Synchrotron radiation theory indicates two possible regimes for CSR production. The well-known equation:

$$\frac{dP}{dw} = \frac{dp}{dw}\left[N + N(N-1)g(w)\right] \quad (1)$$

indicates that, for a given frequency w, the total power P emitted as synchrotron radiation, is given by the combination of an incoherent part, given by the product between the number of particles per bunch N and the single particle emitted power p, and of a coherent part, which is practically proportional to N^2 and to a form factor g given by:

$$g(w) = \left| \int_{-\infty}^{\infty} dz\, S(z) e^{iw \cos(q) z/c} \right|^2 \quad (2)$$

Equation (2) shows that the form factor, which ranges from 0 to 1, is essentially the square of the Fourier transform of the normalized longitudinal distribution $S(z)$ of the bunch. The quantity q is the angle between the longitudinal axis z and the line connecting the source to the observation point. According to equation (1), generating CSR consists essentially in making g different than zero in the frequency range of interest. As anticipated, Equation (2) indicates two possible modes: shortening the bunches down to lengths comparable to the related synchrotron radiation wavelengths or, with significantly longer bunches, 'distorting' the longitudinal distribution in a controlled way in order to have non-zero spectrum components at the wavelengths of interest. It must be remarked that because of the quadratic dependence of CSR on N, which is always a large number, even fairly small values of g can already give orders of magnitude enhancement compared with the incoherent emitted power case. The very promising results obtained at BESSY II [4] seem to belong to the second category. We have started a collaboration with the BESSY II group and we are now working together for a full characterization of the physics behind their results.

Table 1. ALS Far IR Ring main parameters.

PARAMETER	**Value**
Beam Energy [MeV]	300 – 700
Current [mA]	1 – 200
Particles/Bunch	$5\ 10^{6}$ - $1\ 10^{9}$
Ring Length [m]	66
RF Frequency [GHz]	1.499
Harmonic Number h	330
Max. Cavity Voltage [MV]	2
Natural Emittance [m rad]	~ $5.0\ 10^{-8}$
Emittance Ratio	1
Min. Momentum Compaction	< 10^{-6}
Periodicity	6
Dipoles/Quads/Sexts/Period	2/5/6
Bend Radius [m]	1.5578
IR Ports/Bend	3

In designing our CSR dedicated ring for the ALS both the approaches have been pursued. Table 1 shows the ring main parameters and their range of tuning. For the very short bunches a proper combination of low beam energy (300 MeV), high RF voltage (2 MV) and frequency (1.5 GHz) and relatively low momentum compaction ($3\ 10^{-4}$) can in principle give bunch lengths of ~ 70 μm. A critical issue in this regime is the possible lengthening effect and/or instabilities that wakefields can induce on the bunch. In particular CSR impedance seems to play a very important role. A carefully analysis of the effect is being performed thanks also to the collaboration of other people [5]. At the present time a maximum current per bunch of 10 μA has been assumed for this short bunch regime. As an example, Figure 2 shows the potential photon flux gain (~ 5 order of magnitude) that the short bunch regime presents with respect to

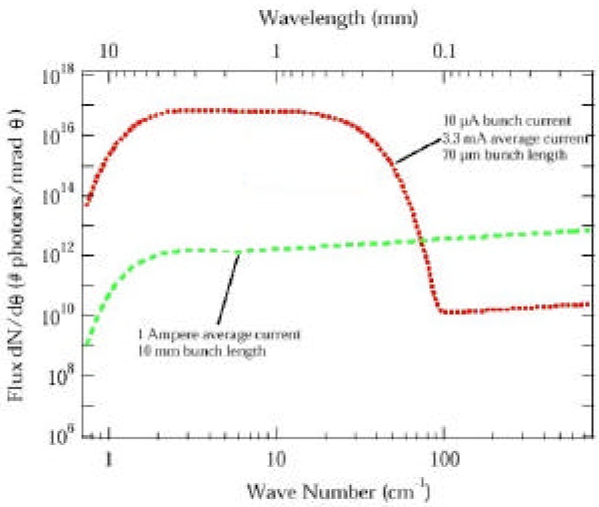

Figure 2: Far IR ring photon flux in the short bunch coherent mode with 10 mA per bunch (red dotted line) compared to the case of a similar ring with longer bunches and 1 A stored current (green dashed

the case of a similar ring in incoherent synchrotron radiation regime with much longer bunches and 1 A stored current. The long wavelength cutoff is due to the vacuum chamber shielding. The RF voltage high value (2 MV) of this mode of operation can be achieved by the combined action of 4 normal conductive cavities or by a single cavity super conductive system. The pros and cons between the two options are still under evaluation.

As far as the 'distorted' bunch configuration is concerned, it must be remarked that the effective action of most of the distribution 'distorting' phenomena (vacuum chamber and CSR impedances, lattice non-linearities) increases in the presence of very low values of the momentum compaction a_c. The BESSY II results [4] are the experimental proof that in this low a_c regime a stable distortion of the bunch longitudinal distribution can be obtained with consequent production of stable CSR. Starting from this observation we are designing our ring with the capability of complete control of this important quantity. A Double Bend Achromat lattice (DBA), see Figure 3, together with a number of sextupole families (and probably some octupole ones as well) will allow the proper tuning of the linear and of the most important non-linear terms of the momentum compaction. The tuning of other important parameters such as beam energy, current per bunch and others will finally permit the optimization of this operation mode.

It must be pointed out that, because in the far IR the source size is diffraction limited, then the requirement of a small transverse emittance is strongly relaxed and it will be possible to operate the ring in full coupling with beneficial effects on the beam lifetime (Touschek).

FAR-IR TRANSMISSION, STABILITY AND MULTIPLE REFLECTIONS

The Far-IR beam lines are being designed to optimize the transmission of the synchrotron radiation at these frequencies. In particular, the dipole magnet vacuum chamber, see Figure 4, presents the very large vertical acceptance angle of 140 mrad (total) that allows 95% transmission of the photons at l = 1 mm. The photons collected by the ~ 300 mrad horizontal acceptance mirror (visible in red in Figure 4) are then split in 3 different beams by the same number of downstream mirrors (not shown in Figure 4).

The peculiar design of this large acceptance dipole vacuum chamber shows an evident cavity like shape that of course resonates at several frequencies. MAFIA simulations have shown that the numerous resonant modes are very weakly coupled

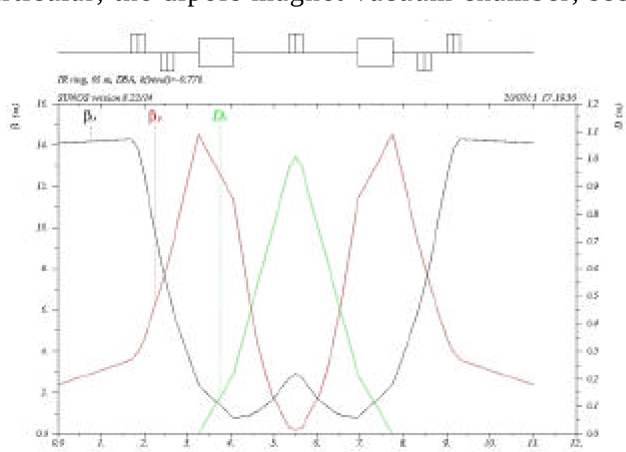

Figure 3: Optical functions in the DBA lattice for the ALS far IR Ring.

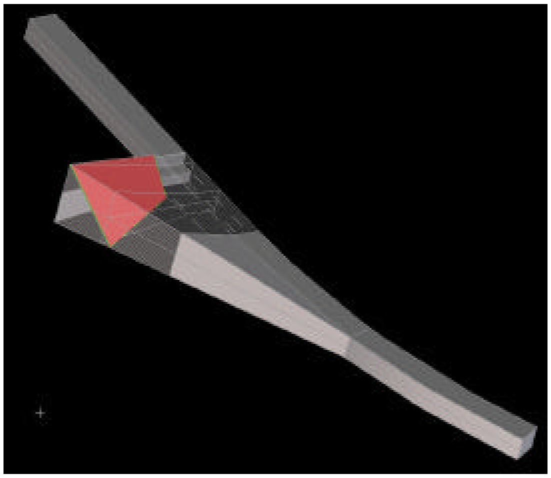

Figure 4: Dipole vacuum chamber and first mirror.

[2] G.L. Carr et al., “Record High Power Terahertz Radiation from Relativistic Electrons” Submitted to Nature (2002).

[3] See for example: Cole, B. E. et al., Nature 410 60-63 (2001); Huber, R. et al, Nature 414 286-289 (2001).

[4] M. Abo-Bakr et al., “Steady State Far Infrared Coherent Synchrotron Radiation Detected at BESSY II” To be published on Physical Review Letters, submitted on October 2001.

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M. Zobov, LNF INFN.

[6] M. Martin et al., “Active Feedback on the Infrared Beamline” ALS 1999 Activity Report pp. 78-79.

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